Current-induced wave modulations observed by a GPS wave buoy deployed near Kozu Island, Japan

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Outline

• Introduction
  – Background and Motivation

• Observation instrument
  – GPS wave buoy (moored and dirifting)

• Results of analysis on the observed data
  – Buoy trajectory, wave hight, wind etc.

• Results of numerical modeling
  – WWIII, simulation with and without currents

• Summery
Introduction

• Background
  – Wave Energy Converter Development Project
    • By Mitsui Engineering and Shipbuilding Company
    • Test site -> offshore Kozu Island
Our Work

- Wave and current observations at the test site

Topics related to the observation

- seasonal characteristics
- island shadow effect
- wave-current interaction
- model validation
- wave power estimation
– Today's topic: Drifting event
  • 81 days (Dec/10/2013 – Feb/28/2014), 2100 km, 28 cm/s
  • Waves around Kuroshio Extension region was observed
    – Wave modulations due to strong currents
• Motivation

  – Getting Knowledge of offshore waves for Kozu project (and other works)
  – Model validation for NEDO potential project
    • Nov/11, Progress on a 20-Year High-Resolution Wave Resource Assessment of Japan
  – Making a description for future data release
    • Buoy trajectory
    • Wave characteristics and related weather condition
    • Wave – current interactions
Measurement Instrument

- GPS Wave buoy

- Wind Sensor
- Solar Panel
- Iridium Antenna
- GPS Unit

**Dimensions:**
- Height: 3.9m
- Diameter: 1.1m

**Weights:**
- Weight: 460 kg
- Buoyancy: 11.7 kN
Drifting condition
- The Buoy was drifted with 120 m rope.
  > stabilize the buoy motion
Analysis on the observed record

Buoy trajectory

buoy trajectory, Dec/10/2013 - Feb/28/2014
Animation: Bouy location and Sea Surface Height

buoy location & AVISO NRT MADT, 00:00 11/Dec/2013
<table>
<thead>
<tr>
<th>Period</th>
<th>Buoy Location</th>
<th>Estimated Forcing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dec/10 – Dec/12</td>
<td>Inshore area of the Kuroshio</td>
<td>Tide, Wind</td>
</tr>
<tr>
<td>Dec/12 – Dec/16</td>
<td>Kuroshio Extension (near axis)</td>
<td>Kuroshio Extension, Wind</td>
</tr>
<tr>
<td>Dec/16 – Jan/10</td>
<td>Kuroshio Extension (southern edge)</td>
<td>Kuroshio Extension, Wind</td>
</tr>
<tr>
<td>Jan/10 – Feb/28</td>
<td>Southern Recirculaion of the KE</td>
<td>Eddies, Wind</td>
</tr>
</tbody>
</table>
Wave characteristics and related weather condition

Time series of SWH (blue) and atmospheric pressure (red)

Wind data is not available due to sensor failure.
-> Atmospheric pressure data is important for understanding weather condition.
Correlation function between AP and SWH.
Positive lag means AP precedes SWH.

Pressure decrease happens 18 hours before increase of wave height.
Wave climate
Color indicates SWH.

Northerly waves are dominant.
Estimation of typical weather pattern

1. Pressure decrease precedes wave growth
2. Northerly waves dominate observed waves.
The low pressure becomes large and strong over the east of Japan. Strong north wind -> High wave height.
Weather Chart by JMA

SWH (m) & Atmospheric Pressure (hPa), Dec/10/213 - Feb/28/2014
Wave – Current interaction

WAVEWATCH III (ver. 4.18)
One-way nested model
Pacific (0.6°x0.75°) -> Offshore (0.2°x0.25°)
NEDO potential project
Wind: NCEP CFSR
Current: no-current, JCOPE2 (and AVISO)

\[
\frac{\partial N}{\partial t} + \nabla_x \cdot \dot{x}N + \frac{\partial}{\partial k} \dot{k}N + \frac{\partial}{\partial \theta} \dot{\theta}N = \frac{S}{\sigma},
\]
\[
\dot{x} = c_g + U,
\]
\[
\dot{k} = -\frac{\partial \sigma}{\partial d} \frac{\partial d}{\partial s} - k \cdot \frac{\partial U}{\partial s},
\]
\[
\dot{\theta} = -\frac{1}{k} \left[ \frac{\partial \sigma}{\partial d} \frac{\partial d}{\partial m} - k \cdot \frac{\partial U}{\partial m} \right],
\]
Animation: Bouy location, simulated SWH & Wind

Buoy location & SWH + Wind, 00:00 11/Dec/2013

Buoy Speed : 1.47 m/s
SWH : 4.0 m
Wind Speed : 16.5 m/s
Impact of currents on simulated SWH along the buoy trajectory.

Basically, ocean currents has very small impact on error indexes.

<table>
<thead>
<tr>
<th>Error index</th>
<th>No current</th>
<th>JCOPE2</th>
<th>AVISO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bias (m)</td>
<td>0.37</td>
<td>0.34</td>
<td></td>
</tr>
<tr>
<td>Unbiased RMSE (m)</td>
<td>0.56</td>
<td>0.55</td>
<td></td>
</tr>
<tr>
<td>C.C.</td>
<td>0.86</td>
<td>0.87</td>
<td></td>
</tr>
</tbody>
</table>
The buoy doesn't move in areas where waves are largely modulated by currents.
Modulation of swell due to the Oyashio and meso-scale eddies.

-> Oyashio Current is also important for simulating waves east of Japan.
Summary

The GPS wave buoy data during the drifting event was analyzed.  
- One of motivation is to make a description of the data for data release

Following things were explained.

i. Buoy trajectory
Buoy trajectory was categorized into four different groups based on the buoy location.  
- Inshore area of the Kuroshio, Kuroshio Extension, Southern edge of the KE, 
  and Southern Recirclation area of the KE

ii. Wave characteristics and related weather condition
Northerly wind on the western side of low pressure over the east of Japan is the 
dominant forcing of the observed waves.

iii. Wave-current interaction
Wave-current interaction is an important factor for simulating the waves around 
KE region. But effect of wave-current interaction on the simulated along-
trajectory SWH is very small.
Acknowledgement

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Modulation of swell due to the Oyashio, Kuroshio Extension, and eddies